# CONCRETE-FILLED STEEL TUBE TO CONCRETE PILE CAP CONNECTIONS – FURTHER EVALUATION/IMPROVEMENT OF ANALYSIS/DESIGN METHODOLOGIES

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## INTRODUCTION

The Montana Department of Transportation (MDT) has found concrete-filled steel tube (CFST) piles connected at the top by a concrete pile cap to be a very cost-effective support system for short and medium span bridges. A typical pile cap using this system is shown in Figure 1. This type of system offers low initial cost, short construction time, low maintenance requirements, and a long service life. While the gravity load performance of these systems is well understood, their strength and ductility under extreme lateral loads (e.g., seismic events) is more difficult to reliably predict using conventional design procedures. This project aims to further develop newly established design and analysis methodologies through experimental testing to ultimately ensure bridge performance is fully consistent with design intent.


Figure 1. Typical MDT concrete-filled steel pile and concrete pile cap bridge substructure support system (Pryor Creek Bridge near Huntley, MT – courtesy of MDT (2012))

## EXPERIMENTAL DESIGN

An experimental program was developed to address the shortcomings identified in this analysis. Specifically, the proposed experimental design varied load setup (testing specimens vertically rather than on their sides, Figure 2), specimen scale, and reinforcement details relative to the original experiments. The results from this test series will be used to further establish the efficacy of the MDT design/analysis methodologies. A total of four specimens were designed and tested in this research.

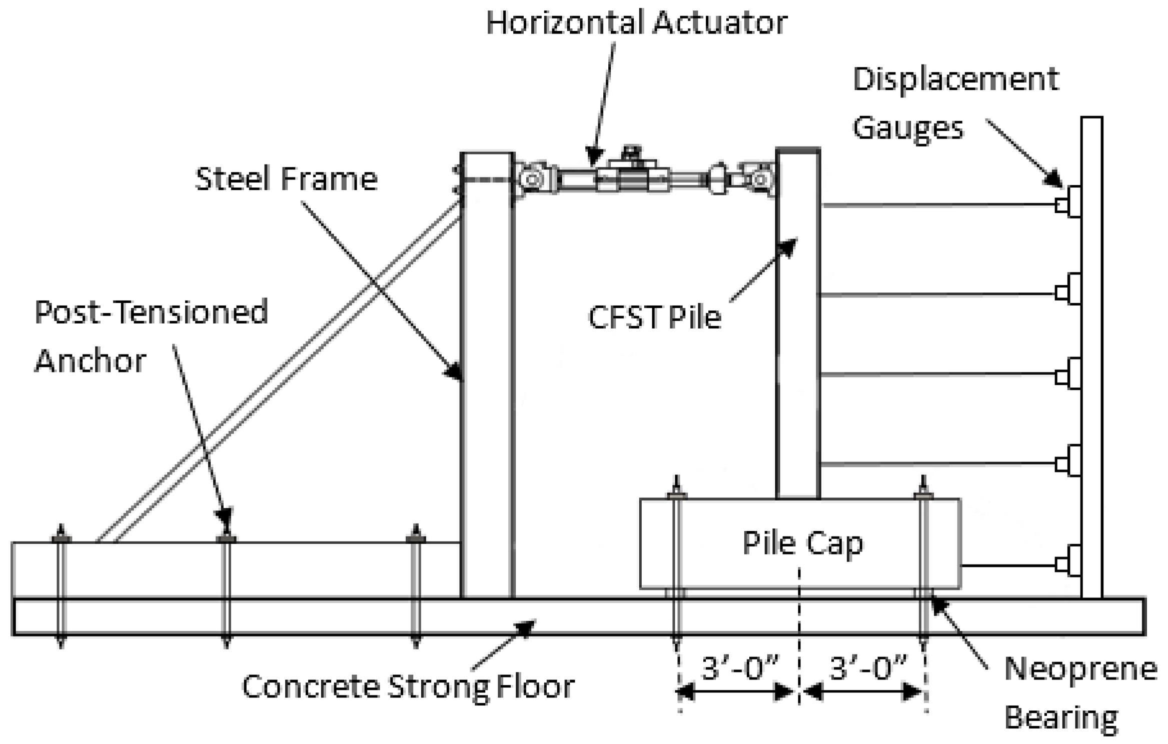


Figure 2. Testing Set Up

## SPECIMEN OVERVIEW

- Specimen 1 – VT1/2-4 ("Verification Test, ½ Scale, 4 ksi Target Concrete Strength") was tested to provide continuity from the previous testing at MSU and determine whether the testing orientation had any large effects on the results.
- Specimen 2 – VT2/3-4 was tested to isolate the effects of specimen size by keeping the concrete strength constant and changing the scale of the model.
- Specimen 3 – VT2/3-6 was tested to isolated the effects of concrete strength by keeping the size of the model constant and changing the strength of the concrete.
- Specimen 4 – VT2/3-4U ("U" indicates addition of U-bars) was tested to observe the effects of adding U-bars around the embedded tip of the pile (Figure 3).

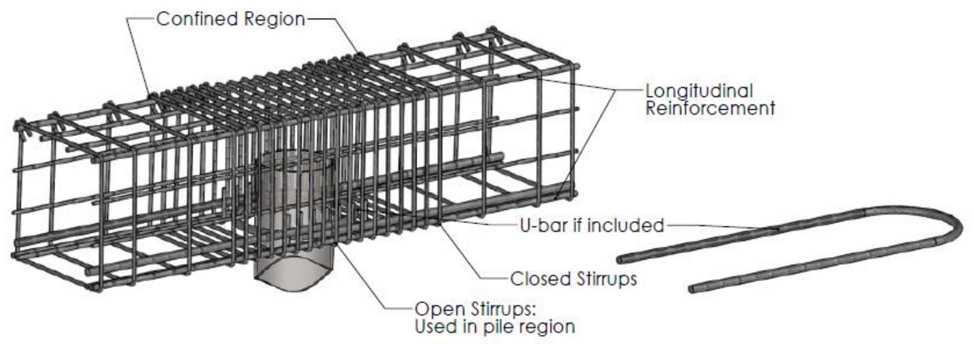


Figure 3. Addition of U-bars to VT2/3-4U

## TEST RESULTS

**VT1/2-4 –** Failed in the pile cap due to a combination of failure mechanisms.

**VT2/3-4 –** Failed in the pile cap due to a combination of failure mechanisms.

**VT2/3-6 –** Failed in the pile cap due to a combination of failure mechanisms.

**VT2/3-4U –** Failure was forced into the CFST, a desired failure mechanism

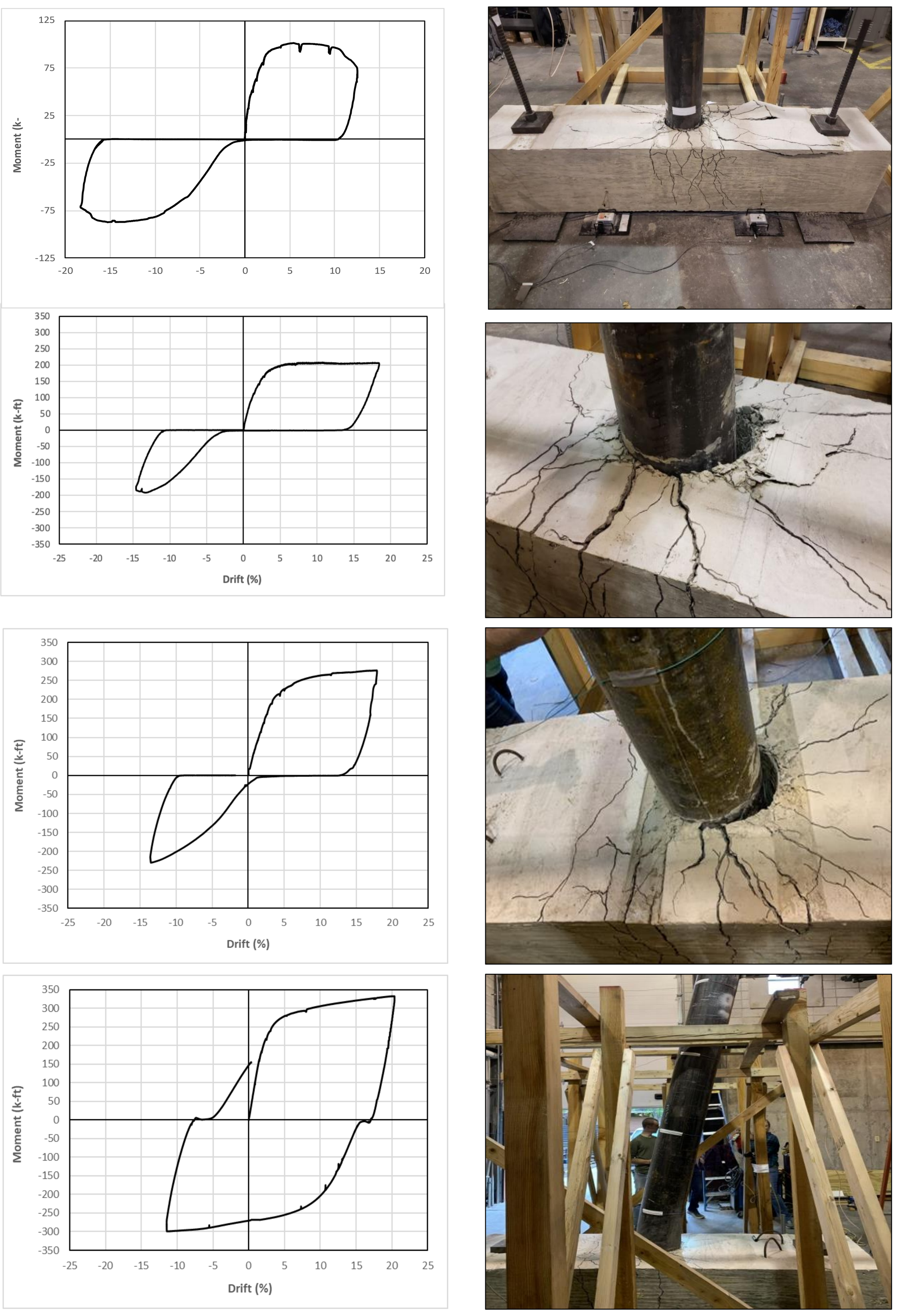

Figure 4. Moment-Drift Reponses Curves (Left) and photos of damage (Right) from each specimen

Table 1. Summary of Results

| Specimen Name | Concrete Strength (psi) | Specimen Scale | Reinforcing Scheme | First Crack Moment (k-ft) | 45˚Crack Moment (k-ft) | Gap Formation Moment (k-ft) | Failure Mechanism | Ultimate Moment (k-ft) | Predicted Moment (k-ft) | Measured/Predicted Ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| VT1/2-4 | 4000 | 1/2 Scale | Normal | 47.3 | 63 | 63 | Cap Failure/Crushing Cracking | 101.5 | 111.9 | 0.91 |
| VT2/3-4 | 4000 | 2/3 Scale | Normal | 69 | 115 | 92 | Cap Failure/Crushing Cracking | 208.3 | 232.5 | 0.90 |
| VT2/3-6 | 5500 | 2/3 Scale | Normal | 92 | 138 | 115 | Cap Failure/Crushing Cracking | 276.7 | 304 | 0.91 |
| VT2/3-4U | 4800 | 2/3 Scale | U-Bars Added | 92 | 184 | 230 | Plastic Hinge in CFT | 332.3 | 301.6 | 1.10 |
| | | | | | | | | | *Average =* | 0.95 |
| | | | | | | | | | *Coeff. Of Variation =* | 0.104 |

## CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this research, the following conclusions were made:

1. Specimens without U-bars demonstrated the same overall moment-drift response, progression of damage, and failure mechanism. This indicated that scale did not affect the performance of the connection (besides the obvious strength and stiffness differences).
2. The inclusion of U-bars forced the failure into the CFST, increasing the capacity (~60%), increasing the stiffness, and positively affecting the energy dissipation capabilities.
3. A 33% increase in concrete strength resulted in a 33% increase in the initiation of damage and ultimate load capacity of the pile indicating that the effect of concrete strength on cap performance may be 1 to 1.
4. Predicted values from the moment-rotation methodology were compared to the measured values and the average measured-to-predicted ratio was 0.95. It was determined that the methodology tends to overpredict capacities for connection without U-bars and underpredict the capacities for those with U-bars.

The results of this research provide substantial insights into the behavior of CFST to concrete pile cap connections under various conditions and validates the use of the moment-rotation methodology as a reliable tool for capacity prediction.

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